THE COMPARISON STUDY OF SIGNIFICANT WAVE HEIGHT ESTIMATION OVER OPEN-OCEAN AND COASTAL WATERS USING SENTINEL-1 SAR

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ABSTRACT - As the waves propagate closer to the shoreline, the decreasing water depth may result a bottom drag effect, causing changes on wave propagation mechanism, including the wave shape. In the transitional waters, known as the areas between the deep and shallow waters, the linear wave theory is widely used to describe the hyperbolic increment of wave height. Sentinel-1 SAR system is one of the most recent satellite systems known for its capability of resulting a robust estimation of the Significant Wave Height (Hs). Yet, the estimation performs inferior on the transitional and shallow water. We improved a previously developed a semi-empirical algorithm to estimate a transitional water, by integrating the in-situ bathymetric information with the state-of-the-art parameters such as azimuth cut-off wavelength, peak of dominant wavelength, and the wave propagation devia tion from the radar-looking direction. We also proposing the utilization of cross-polarization to enhance the wave pattern contrast on the co-polarization. To improve the dominant wavelength peak on the two-dimensional wave spectra, adaptive statistical fitting and parameterized median filtering method are applied ensures a statistically robust determination of the filtering parameter, resulting in a higher contrast SAR image that allows clearer wave patterns and more efficient dominant wave peak identification. The bathymetric and standard meteorological information from National Buoy Data Centre (NDBC) measurement buoy are used in development of the semi-empirical model, from the water depth input through validation process. This research employs Level-1 GRD Sentinel-1A SAR around Hawaii water for the open-water scenario, and the Channel Islands on the West Coast of the USA for the transitional water scenario, for the year of 2017. Extreme sea states are not considered due to the limitation of our algorithm, image repository and buoy data availability.

INTRODUCTION - We investigate and improve a previously developed semi-empirical algorithm that may improve the accuracy of Hs estimation at open-ocean locations and coastal waters applied to Sentinel-1 SAR without prior knowledge or external inputs based on Wang, et al. (2012). Several new approaches are listed as follows: [1] Developing a routine for Hs estimation algorithm, covering three possible modulation (tilt, hydrodynamic, and velocity bunching) with the fair-use over the open-ocean and coastal waters in non- extreme condition; [2] Applying necessary pre-processing strategies (sub-setting, digital filtering, and regression method) for better estimation of Hs ; [3] Detailed sensitivity analysis of relevant SAR-derived parameters and environmental variables that may influence the estimation of Hs; specifically, differing wind forcing, dominant wave type, seasonal change, and bathymetric influence

METHODOLOGY - Our interest to understand the wave dynamics will focus on linear Airy wave theory (Airy, 1845). We used the semi-empirical algorithm that widely known to have a simple computation yet complex usage of the theoretical and empirical SAR-derived parameters. The basic algorithm is developed through Wang, et al. (2012) for the deep-water wave, but we added several modification and future replacement of variables with low consistency and low correlation towards the buoy derived Hs. We only use scenes with a pure and visible ocean wave pattern eliminate the image contamination effects of current shears, oil slicks, ships, or islands. The normalized mean intensity variance is denoted by cvar_vv, shown below (Mouche and Chapron (2015), Stopa, et al. (2017), and Wang, et al. (2018)

$$cvar = var\left(\frac{I - \langle I \rangle}{\langle I \rangle}\right)$$

where <*I*> is the mean intensity of a scene subset data. In general, scenes with weak ocean wave modulations or dominated by speckle noise, will exhibit a normalized mean intensity variance that is small and close to 1.0. The homogeneity of our images is enhanced by limiting the normalized variance to the range of 1 cvar 2.

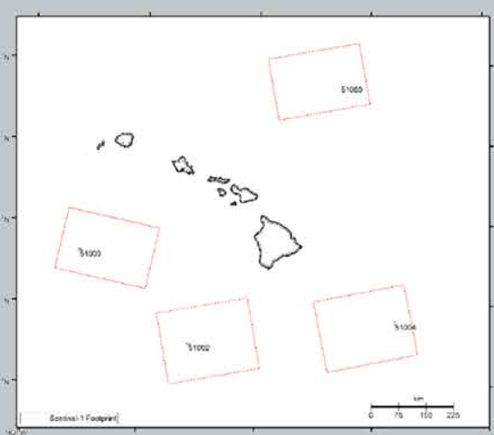
The final equation is summarized as follows:

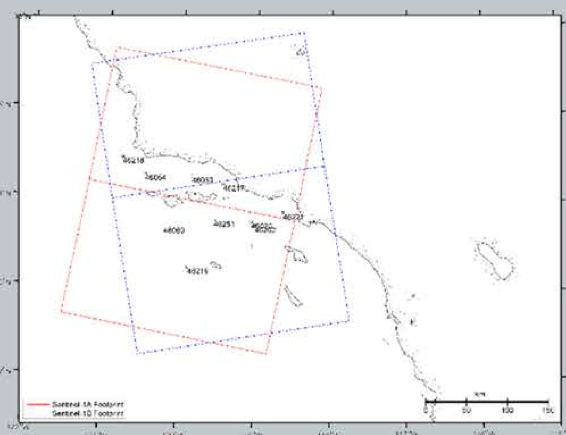
$$H_s = C\,\frac{2.88}{\beta\sqrt{g}\sqrt{tanh\,2\pi d/\lambda_p}}\,\lambda_{co}\sqrt{\lambda_p}$$

$$C = \frac{1}{\sqrt{1 - 0.5\,sin^2\theta\left[1 + \frac{(2\pi/2B)}{sinh(2\pi/2B)}(2\psi)\right]}}$$

This algorithm works through three prerequisite empirical parameters, which are the peak of dominant wavelengths (λp), the wave propagation deviation for the azimuth direction (ψ, where ψ = 0 for azimuth travelling waves), and the azimuth cut-off wavelength (λco). d is the water depth taken from the NDBC buoy and Θ is the incidence angle

Our region of interest for this research are Hawaii Waters, for the open-water scenario, and Channel Islands on the West Coast of the USA, for the coastal water scenario, for the entire year of 2017. Currently, the routines are covered only 40% of all the available stations, covering station 51000 to 51004, 46219, and 46069 with ≈ 140 scenes available, and would be extended in the future.





The routines are divided into two parts, deriving three parameters. The peak of dominant wavelength, λo, are estmated by taking the 2-dimensional discrete Fast Fourier Transform (2D-DFFT) from a digital image. Afterwards, the azimuth cut-off (λco) is obtained by fitting a Gaussian function to the autocovariance function (ACF) of the cross-spectrum image for zero range lag. ACF is obtained by the inverse fast Fourier transform of the azimuthal section power spectral density (PSD) associated to a selected squared image subset (Bendat and Piersol, 2012; Grieco, et al. 2016). The median filter with dynamic window size are also applied to the resulting ACF in order to remove the speckle noise peak at the center or the spectra (Goldfinger, 1982)

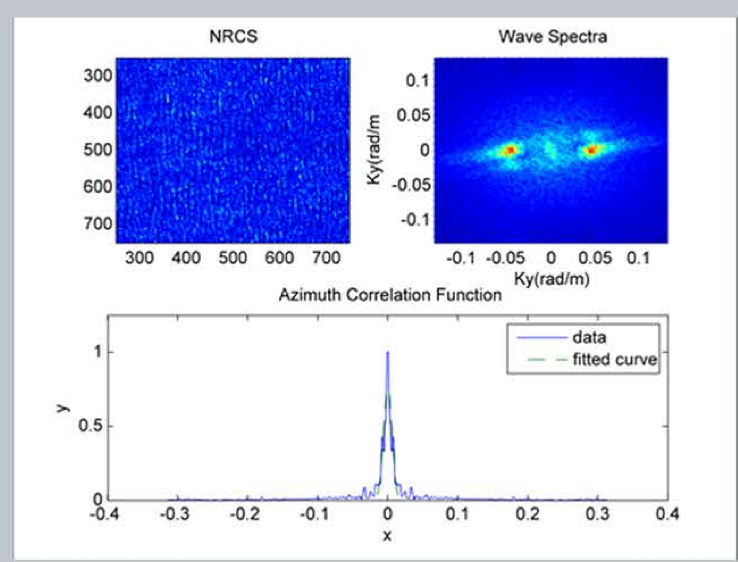
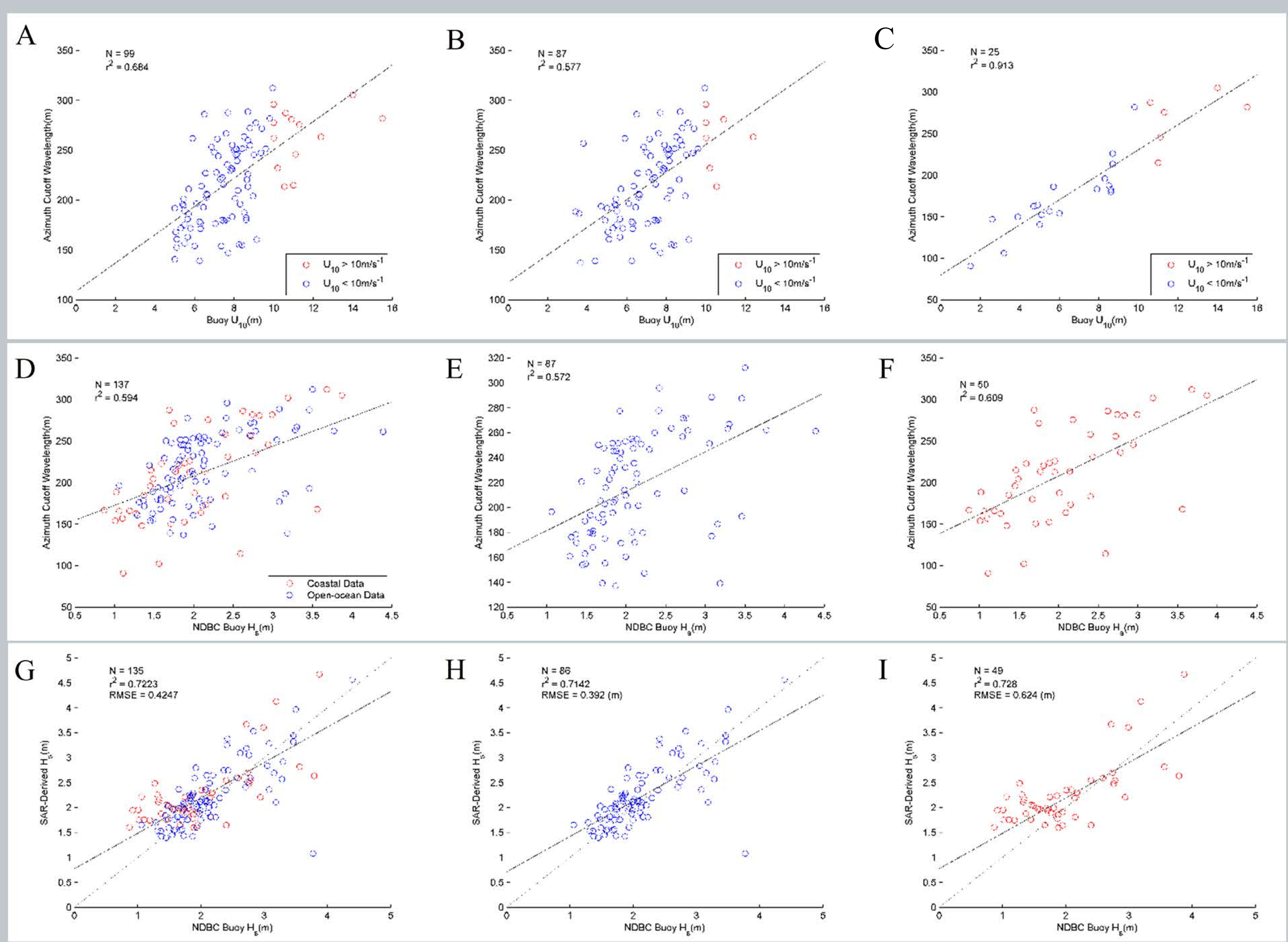
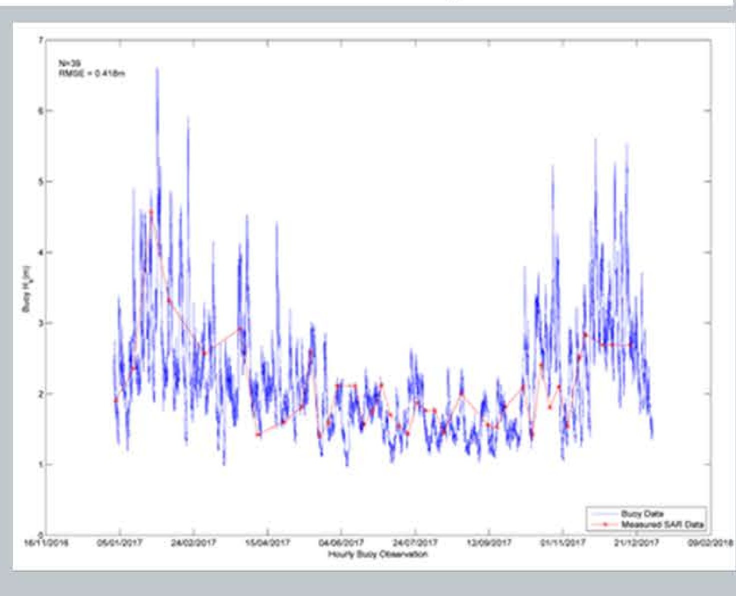


Figure below shows the overall result with correlation of estimated Azimuth cut off wavelength to the buoy-derived U10 on all data points (a), open-ocean (b), and coastal waters(c); and to the buoy-derived Hs on all data points (d), open-ocean (e), and coastal waters(f); and estimated significant wave height to the NDBC buoy on all data points (g), open-ocean (h), and coastal waters(i). It shows both usability of the semi-empirical equation used and may explain and improve our understanding how Sentinel-1 system visually respond in imaging wave in off-shore and coastal location, trough many sea condition, which are mainly influenced by wind, such as wind speed and wave type.



Our linear approximation method is found to be effective in estimating Hs for any wave type (i.e., swell or fetch), though higher wind conditions (i.e., U10 > 10 ms-1) can introduce more errors. The reliability of using the Sentinel-1 for annual analysis is shown from the right figure of Actual data stream or Sentinel-1A and B SAR collocated with NDBC station 51000 for one-year time span of 2017. Since the discrete Hs obtained using SAR image is received only 2-3 times monthly, the full spectrum of the highest and lowest possible Hs could not be retrieved. But, the seasonal variance is clearly shown trough the plot below



Main References

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